

Technical Comparison of AgION Antimicrobial to Nanoparticulate Silver

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Nanoparticulate silver is a recent addition to the group of technologies designed to use silver as an antimicrobial. The strategy uses very fine particles of silver blended into plastics to impart antimicrobial activity. However, the fine particle size limits the available silver reservoir and the particles that are exposed must provide silver by oxidizing and dissolving, a process that is highly variable and very dependent on the environment in which the part is used.

The Reservoir Model

The primary indirect indicator of performance in antimicrobial surface engineering is the quantity of active ingredient available at the surface. This quantity, the *silver reservoir* in the case of silver based inorganic antimicrobials, can be both calculated and measured. The calculation involves the obvious variables of Ag loading in the antimicrobial additive and the additive loading in the plastic or coating. However, following is an illustration of how the particle size is also a significant variable.

On first thought, the total silver content of the plastic is a logical metric to use to compare particulate antimicrobials. It can easily be calculated by multiplying the Ag content of the particles by the particle loading in the material. However, when that is plotted against the measured silver reservoir available from the surface, determined by

performing a serial extraction, the plot in Figure 1 is obtained.

Four different types of antimicrobial additives were used for this experiment ranging in particle size, silver content and loading in the plastic. Based on silver content in the plastic, a logical metric of expected performance, at first glance, there is no correlation to the Ag reservoir, the indicator of performance.

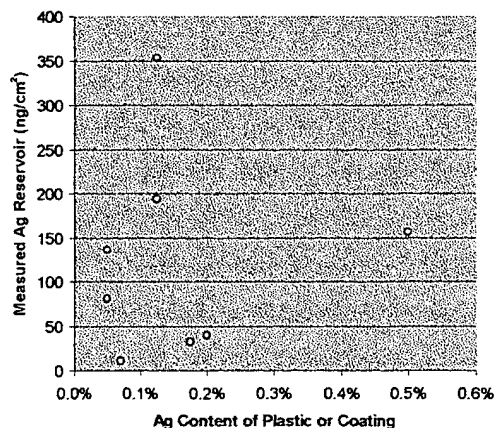


Figure 1: Comparison of the Ag content of the plastic to the available silver measured

through serial extraction. Note the lack of correlation.

Now consider the schematic diagram in Figure 2, in which particles are embedded in a material near the surface. Only the top layer of material, to the depth of one particle diameter, contains available silver. Particles deeper into the polymer are not in contact with the surface and therefore cannot deliver silver and provide efficacy.

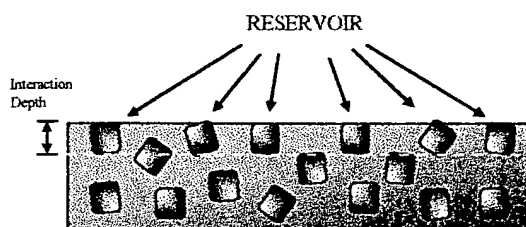


Figure 2: The available silver reservoir in a material containing a particulate additive

Therefore, we can calculate the reservoir in a one square centimeter area with the formula,

$$R\left(\frac{\text{ng}}{\text{cm}^2}\right) = D(\mu\text{m}) \cdot C(\%) \cdot L(\%) \cdot 10^5$$

If the same data from Figure 1 is recalculated to account for particle size as in the equation, the plot in Figure 3 is obtained.

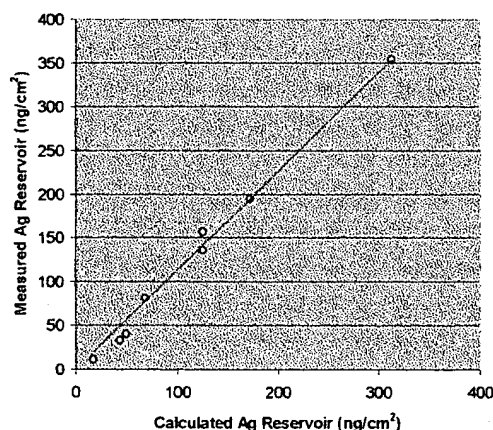


Figure 3: Measured Ag reservoir showing correlation with the reservoir model

accounting for additive Ag content, additive loading in the plastic, and particle size.

The calculated reservoir data matched the measured data with a correlation coefficient of 99.6%, indicating a highly predictive model.

Explaining the particle size effect

The reason that particle size has such a strong effect on the accuracy of the model can be illustrated in the diagram in Figure 4. The diagram represents two plastic parts that contain the same loading of additive, one large particle size material, one smaller particle size material. In the diagram, the combined area of the two dimensional particles (circles) in the top material is equal to that in the bottom material, which serves as an analogy to the three dimensional case of equal loading, but different particle size.

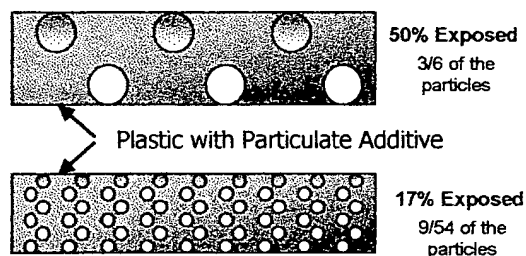


Figure 4: Schematic diagram illustrating the influence of particle size on surface access relative to loading. These diagrams represent identical "loadings". In the top figure 50% of the powder added is exposed, in the bottom figure, only 17% is exposed.

From the diagram it is apparent that, for the larger particles, a greater percentage of the material added to the plastic is in contact with the surface (shaded), than for the smaller particles.

We can see the effect of this difference by measuring the silver reservoir in a variety of samples with different particle sizes and loadings of different additive

grades. The chart in Figure 5 presents the calculated and measured silver reservoir in samples loaded to 2% with an antimicrobial having a submicron particle size and two different silver contents, and AgION grades with larger particle size and lower silver content.

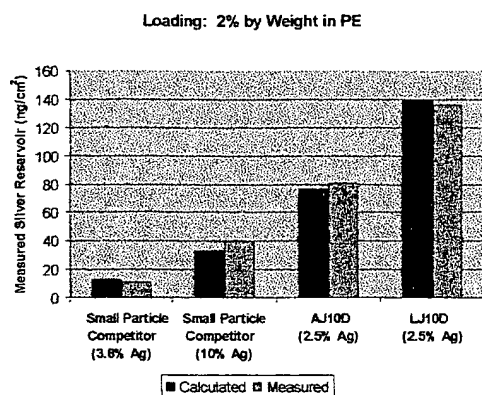


Figure 5: Test results showing how smaller particles provide less available silver even though the particles have higher Ag content

The small particle grades have significantly higher silver loading, yet fail to release nearly as much silver as the lower Ag content AgION grades. The clearest example of the particle size effect in this diagram is the comparison of AgION grades AJ10D and LJ10D. The two grades differ only in particle size and the larger LJ10D grade provides nearly twice the silver reservoir.

Nanoparticulate silver materials range in particle size, but are generally smaller than 100 nm in diameter. Typical grades are 25-70 nm in diameter, which as demonstrated above, results in only a small portion of the additive being exposed at the surface. Using the same model as described above and comparing nanoparticulate silver to AgION products, the value of an optimized particle size becomes apparent (see Figure 7).

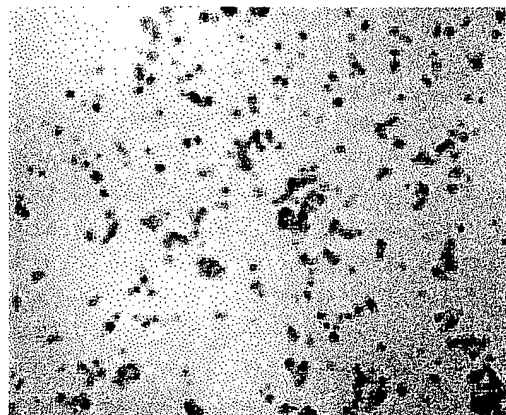


Figure 6: Transmission Electron Microscope image of nanoparticulate silver showing the very small particle size.

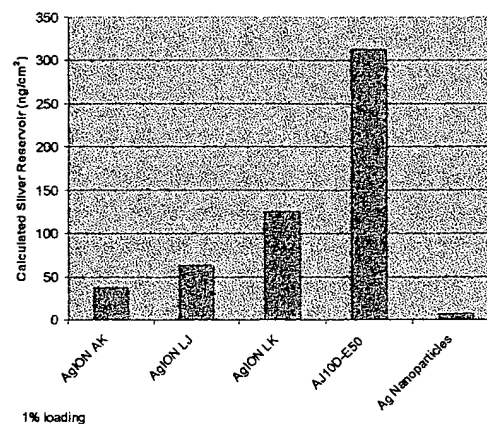


Figure 7: The available silver reservoir for AgION and nanoparticulate silver (at 1% loading in a plastic) demonstrating that the AgION particles have much more available silver.

Furthermore, for the silver to become ionic, which is required to control bacteria, the metal particles must oxidize and then the oxide must dissolve. Metallic silver dissolution by this mechanism doesn't readily occur, obviously, since we know silver jewelry and silverware don't dissolve. In general, dissolution is a poor release mechanism because it is very sensitive to the environment in which the treated part resides. Temperature, flow rate, pH and

other dissolved species have a significant effect on the kinetics of dissolution. In particular, acidic solutions greatly increase the solubility of silver oxide, and therefore, can deplete the surface of silver very quickly.

To test the stability of the silver nanoparticles, samples of ABS plastic containing nanoparticulate silver were soaked in a 0.7% to extract all the exposed silver and determine the available reservoir. One set of as-molded samples were soaked for 20 min and 24 hours in Coca Cola, another set in orange juice for the same times. The results of the experiment are shown in Figure 8, and demonstrate that the silver is rapidly dissolved from the surface in a very short time under conditions that are not unusual in normal applications.

In conclusion, the particle size and metallic form of nanoparticulate silver makes it unsuitable for use in applications where varying chemistry, challenging microorganisms, wet environments or long term applications – all environments in which AgION Antimicrobial regularly demonstrates high levels of efficacy.

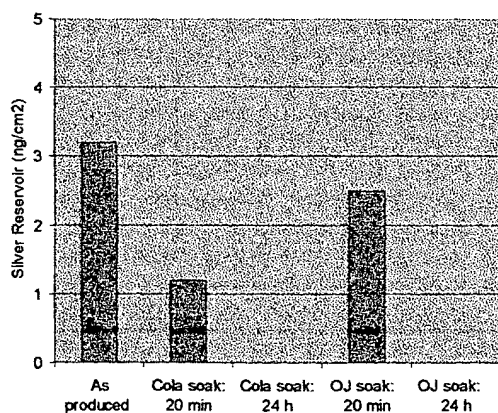


Figure 8: Depletion of the nanoparticulate silver reservoir in ABS plastic by common acidic beverages.

The vulnerability of nanoparticulate silver to environmental conditions greatly limits its use in “real-world” applications. Few products can be guaranteed to experience only a narrow range of environmental conditions.